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NATIONAL RESEARCH ON SPACE DEBRIS

SAFETY OF NUCLEAR-POWERED SATELLITES

PROBLEMS OF COLLISIONS OF NUCLEAR POWER SOURCES WITH SPACE DEBRIS

Note by the Secretariat

Addendum

The present document contains information provided in replies received from Member States up to 19 February 1993.

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GERMANY

[Original: English]

SPACE DEBRIS: REVIEW OF WORK DONE IN GERMANY

Germany has yearly submitted working papers on national research activities in the field of space debris to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space. The last working paper is contained in document A/AC.105/510/Add.2 of 26 February 1992. The present working paper reports on the work done since then.

German activities in the field of space debris research cover a wide range. An assessment of all these national activities was presented in a workshop organized by the German Space Agency DARA on 9 December 1992 under the title "Space Debris Research in Germany and Problems of International Regulation". The wealth of German research activities can be grouped under the following areas:

- methods of debris detection;
- modelling of space debris;
- trend analysis;
- investigation of hypervelocity impact phenomena;
- test and numerical simulation;
- development of debris protection systems;
- debris prevention and removal.

German research activities can be distinguished in that they are either conducted on a purely national footing or they are funded under contracts with the European Space Research and Technology Centre (ESTEC) and the European Space Operations Centre (ESOC) of the European Space Agency (ESA).

The nationally funded activities are largely concentrated in the Institute for Space Flight Technology and Nuclear Reactor Technology of the Technical University of Braunschweig (IfRR/TUBS) and the Research Establishment for Applied Science (FGAN) under research contracts awarded by the German Space Agency DARA.

The work at IfRR/TUBS is concentrated on modelling the low-Earth-orbit (LEO) space debris environment. Most of the work is performed in close and successful cooperation with researchers at the United States National Aeronautics and Space Administration (NASA). Two results can be highlighted:

(a) Investigation of the cascading effect of collisions (secondary collisions by debris from a first collision), analysed by aid of a new developed tool, has proved that this is a real and serious process which will set in within two decades from now. In some altitudes the critical density for this process may have already been reached. Preventive measures and their cost have also been analysed;

(b) Modelling of the smaller-particle-size population and comparison with recent measurements (Long-duration Exposure Facility (LDEF)) reveals that the debris source terms used so far have deficiencies. There are more small particles and on higher elliptical orbits than described by our past models for explosions. Obviously other high energetic effects must have contributed to the small-size debris population. The modification of models is in progress.

At FGAN a powerful radar is used to investigate physical characteristics of selected space debris. ESA/ESOC is currently negotiating a contract with FGAN about the detection of small-size space debris with radar.

Additional ESA-funded activities concentrate on meteoroid/debris-protection systems especially in the framework of the Columbus programme. Also covered are investigations of hypervelocity impact phenomena by test (Ernst-Mach-Institut) and numerical simulation as well as improvement of test facilities (Battelle-Institut) in order to reach higher velocities.

Further activities are funded by the German aerospace industry in the field of protection systems, using its own resources.

From 5 to 7 April 1993 the First European Conference on Space Debris, organized by ESA, will take place at Darmstadt, Germany. The German Space Agency is co-sponsoring this conference, which demonstrates the particular attention Germany focuses on the problem of space debris.

The following describes the work in more detail.

I. SPACE DEBRIS MODELLING

Assessing the present and future risk posed to all space objects by the space debris environment requires the use of models. The ESA space debris reference model is currently developed at IfRR/TUBS.

Model outputs are:

- Estimation of the present and future number of trackable and non-trackable debris objects;

- Determination of their spatial distribution;

- Determination of the current and future risk of an impact on a space object orbiting in the debris environment.

Information about the current risk is used as an input for protection measures already needed, especially for manned missions. Of even more importance is the future projection of the space debris environment made with the help of models. It can serve as a basis for discussions and proposals concerning changes of future space flight policies.

Ongoing research work has focused on the consolidation of already existing model components into a fast and handy programme tool, which now allows the simulation of varying future scenarios within a short time. The determination of the spatial distribution of debris has been extended from a one-dimensional to a three-dimensional interpretation. The proposal of a modified mass distribution approach for fragments generated by explosion and collision events has led to a better agreement between modelled and measured debris data.

II. VALIDATION OF SMALL PARTICLE MODEL WITH LDEF DATA

Besides the model for large objects (> 1 cm) as described in the previous section, IfRR/TUBS also developed a model for small particles in the millimetre and 0.1 millimetre size range by taking 31 high-intensity explosions and collisions into account. As new data become available, the model must be validated and, if necessary, updated. The Long-duration Exposure Facility, recovered in January 1990, is a significant new source of data which can be utilized to evaluate the present low-Earth-orbit particle environment and to test the validity of existing models.

A technique has been developed which can be used to derive the general relationships between particle orbits and crater distributions over LDEF surfaces. 1/, 2/, 3/ Applying this technique, the debris model has been compared with the data from 1/ and 2/. While the flux level is in good agreement, there is still some discrepancy in the surface distribution. On the assumption that small debris objects are mainly orbiting at i = 100° (near circular or/and highly elliptical), the agreement is excellent, with the exception of the trailing side. It can be concluded from the measured flux on LDEF's trailing surfaces that small debris particles on highly elliptical orbits with low inclinations are much more abundant than represented in the model.

III. COLLISION-FREE ORBITAL OPERATIONS

Since the risk reduction by the use of shielding (cf. chap. VI below) is limited to impacting objects smaller than approximately 1 cm in diameter, other techniques have been examined at IfRR/TUBS in order to avoid collisions with larger objects which are deterministically known. Besides the procedure of active in-orbit collision avoidance, e.g., changing the orbital period of a spacecraft, so that the point of a predicted collision is passed to another

time, an important and much easier task is the collision-free path durig ascent and first-orbital revolutions of a launched spacecraft.

Currently such a procedure is possible concerning the catalogued objects larger than 10-30 cm in diameter. During an ongoing study a fast computer code has been developed that has the capability to determine possible collisions between a spacecraft to be launched and a member of the existing catalogue. If a collision is predicted (considering the relevant uncertainties during orbit propagation) the launch can be delayed (within a few minutes), so that a collision-free ascent and operation during the first revolutions is guaranteed. Besides the advantages for the launcher of the new spacecraft, other space users will become aware of possible collisions with new objects, if this technique is performed prior to each launch of a spacecraft.

IV. COLLISIONAL CASCADING EFFECTS

The way space flight activities have been performed up to now has resulted in a steady increase of the Earth-orbiting population at a rate of about 5 per cent per year. A steady increase of the number of objects within a limited space, as represented by LEO, must sooner or later lead to the exceeding of the critical density for a collision cascading effect.

Detailed analysis conducted at IfRR/TUBS has shown that the current population level might already be critical in this regard. Assuming the continuation of the current rate of increase, the critical population level will be exceeded for certain within the next 20 to 50 years. This basic tendency is independent of all possible uncertainties. This could be proved by detailed investigations, as the collision cascading effect is absolutely dominated by the deterministically known population of larger, catalogued objects. 4/, 8/, 9/

Also, the technical feasibility and the effectiveness of various countermeasures to avoid a cascading effect of collisions as well as their cost-effectiveness have been investigated. 8/, 9/ The main results are:

- The prevention of explosions (by venting of the propellant tanks) is nearly free of recurring costs and has the highest short-term effect on the reduction of the number of objects in orbit;

- But the only way to prevent collision cascading effects in the long term is the limitation of the number of large objects in orbit by the de-orbiting of payloads and rocket upper stages at the end of their missions. This would cause an increase in launch costs per kilogram of from 5 per cent to 15 per cent for orbits in LEO and in the geostationary transfer orbit (GTO).

Another important problem is the "invisibility" of collisions and of the possible setting in of a cascading effect: 8/

- At the moment, about four fragmentations are occurring per year, for 1961 to the present (112), about 25 per cent of which are classified as "fragmentations of unknown cause";

- Three to five of these have to be suspected to be accidental collisions, but could not be identified directly as such, because both colliding objects were not catalogued by the United States Space Command (USSPACECOM), i.e., larger than some 10 to 50 cm;

- An indirect identification, i.e., the discrimination between explosion and collision by means of ground-based measurements of the generated fragment clouds, is not possible at the moment;

- Hence, accidentally occurring collisions, possibly indicating the setting in of a cascading effect, will not be discovered as such - they will remain "invisible", misinterpreted as "fragmentations of unknown cause".

Investigations are under way to define experiments/measurements, probably in situ, for the identification of single collision events in Earth orbits and the early detection of a possible setting in of a cascading effect.

V. ACTIVE REMOVAL OF LARGE SPACE DEBRIS WITH THE HELP OF A SPACE TETHER

The increasing number of space debris objects endanger already current space flight activities. Concerning the future evolution of the population, the large objects are of decisive importance, because they are the potential sources for the setting in of a chain reaction of collisions, as has been described in detail in document A/AC.105/510/Add.2. If preventive measures are not sufficient to avoid this cascading effect, active removal of numerous (several thousands) large objects from high altitudes (between 700 and 2,000 km) can become necessary. Because this is not feasible using conventional methods, a new strategy called TERESA (TEthered REmover SAtellite) has been developed at IfRR/TUBS. 5/, 6/ The strategy for the removal of numerous large objects from Earth orbit basically consists of the following manoeuvres:

Phase 1 Rendezvous and docking with the selected target object;

Phase 2 Transfer of orbital energy from the debris object to TERESA with the help of a (conductive) space tether;

Phase 3 Adjustment of an elliptical, optimized transfer orbit with the help of conventional or electrodynamically generated thrust;

Phase 4 Separation of the space debris object, i.e., initiation of its reentry (de-orbit manoeuvre); after the separation TERESA's orbit is very similar to the orbit of the next target object.

Thus, the basic idea is a kind of optimized cycle, consisting of energy transfer and energy conversion with the help of a tether. This strategy has been investigated and improved, and a preliminary configuration has been developed in cooperation with German Aerospace (DASA/ERNO).

VI. SHIELDING AND IMPACT ANALYSES

In the past, spacecraft were not designed to withstand debris impacts. But for future space systems, especially manned systems, protective measures are absolutely necessary.

Germany, with DASA/ERNO as prime contractor for the Columbus Attached Pressurized Module (COL-APM) - which is attached to the International Space Station Freedom - is expending much effort in shielding this module against debris impact. The primary structure of the International Space Station and, therefore, also of the COL-APM, shall remain operational in orbit for 30 years. For pressurized modules it is required that they not burst following a meteoroid/debris (M/D) impact according to the environment derived from certain probability requirements, as defined in the system requirements document. The meteoroid and debris protection requirements are some of the driving forces of the design.

In this context, a meteoroid and debris protection study has been initiated by ESA/ESTEC, carried out in international cooperation by DASA/ERNO with subcontracts for ALENIA (Italy), the Ernst-Mach-Institut (EMI, Germany) and Det Norske Veritas (DNV, Norway). This study investigated in more detail the meteoroid and debris impact phenomena and supported the development of the Columbus protection systems.

As one of the problematic areas, it can be stated that a burst of the pressurized module is by far the most severe failure mode. Only a few initial tests could be performed with pressurized plates, with the result that the dynamic effects that did occur were not expected with this extent of damage. This is confirmed by NASA, which has performed more systematic investigations, including tests on pressurized shells.

Any burst caused by an M/D impact must be prevented by an adequate design, subject to rigorous control within the fracture control programme.

DASA/ERNO has submitted a proposal to ESA to investigate the conditions of no burst under M/D impact.

Another ESA/ESTEC study with EMI as subcontractor to Engineering Systems International (ESI, France) was started to assess the capacity of computer codes to describe quantitatively the key parameters of the impact damage. The use of computer codes to simulate hypervelocity impacts is required due to the limitation of test facilities. Impact tests with the light-gas-gun at EMI have been performed for calibration of the mathematical model. This light-gas-gun is one of the most powerful of its kind in the world and is very well suited for the investigation of the hypervelocity impact phenomena.

A further ESA/ESTEC study with Battelle (Germany) was initiated to assess the feasibility of methods to allow acceleration of 1g projectiles to velocities above 10 km/s by using shaped charge techniques.

At IfRR/TUBS, double-wall shielding concepts are being analysed and a computer code, known as DAMAGE, has been developed. It is not so much focused on the real design of protection systems, but rather on how the protection systems can be optimized under consideration of the debris flux angular and velocity distributions. The expected debris impacts are not randomly distributed over the module surfaces of a manned space station module. Therefore, a uniform protection shield is not optimal. By means of the DAMAGE code, a protection shield fitted to the local risk probability can be proposed which reduces the shield weight, but fulfils the same safety requirement.

VII. RADAR DETECTION AND MEASUREMENTS OF ORBITAL DEBRIS

A. Physical characteristics of space debris

Explosions and collisions in space are the major source of orbital debris. The debris fragments pose a hazard to large spacecraft planned to operate for long periods of time. The objective of a NASA/FGAN joint research investigation (DARA contract) is to characterize and compare debris shape, size, intrinsic motion, mass and orbital lifetime from different types of breakups, for example, from collisions and from explosions.

FGAN radar systems (narrow-band as well as high-resolution radars) have been used to measure a collection of 16 different larger debris objects. Narrow-band radar signatures were analysed and radar images have been computed 10/, 11/ to obtain initial results about shape, size, attitude and mass. Methods to assess orbital lifetime, ballistic coefficient and drag factors of space objects were developed. They have been tested with FGAN radar data stemming from observations of decaying spacecraft. 12/, 13/, 14/

A statistical analysis of a measured radar cross-section and a comparison with NASA results derived from effective areas of infrared, optical and radar measurements have been started.

B. Radar detection of small-size space debris

The orbital debris situation is of concern to the construction and operation of spacecraft in low-Earth orbits (LEO). Models have been formulated to describe the debris environment. The models are needed for the engineering design of spacecraft and assessment of mission risk. Non-availability and lack of data together with a limited understanding of the generation of debris are responsible for severe uncertainties in these models. It is hoped that additional measurements and better modelling will reduce some uncertainties, but the prediction accuracy of future space activities of space-faring nations has a major influence on the validity of modelling results.

The study (ESA/ESOC contract) will focus on the definition of special radar observation and processing techniques which will enable the detection and tracking of cm-size objects in LEO using the existing or upgraded FGAN High-power Radar System (34 m antenna, L-band tracking, Ku-band imaging).

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